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DECISION AID FOR DETERMINING THE

ACCEPTABILITY OF BASE-LEVEL

COMPETITIVELY BID CONSTRUCTION PROJECTS

THESIS

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Abstract

The differences between government estimates and contractors' low bids have been such a problem for construction projects that a special Cost Analysis Improvement Group was established in 1973 by the Secretary of Defense. An Air Force study as late as 1984 indicated that 50 percent of the government estimates reviewed were still outside the Federal Acquisition Regulation (FAR) criteria of plus or minus 20 percent of the project's low bid. This research was designed to apply statistical techniques to local construction cost data to develop a system to help determine the acceptability of low bids.

Local, historical, contractor prices were reviewed for minor construction projects under 5,000 square feet. Based on the contractors' progress reports, the low bid prices were broken down by square foot costs into the sixteen divisions of the Construction Specification Institute format for analysis. Several techniques were tested to forecast costs including mean square footage costs, summation of average division costs, summation of median division costs, bid simulation, multiple regression, and time series forecasting. Two test groups were used. One included all the projects in the data base and the second group included only facilities classified as administrative.

Each of these techniques can be used to developed a range of estimated, acceptable costs. The more work elements used and the more uniform the projects, the better the statistical estimate and the estimated range of values. Although these methods show promise for use in developing a technique to assist in verification of acceptable low bid prices, additional research must be done to further validate the results. The small data base and the resultant wide variance of prices enlarged the confidence interval beyond the FAR allowance.

It is recommended that more research be accomplished using these techniques at different locales, with additional projects, and more uniform test group definitions. The multiple regression technique could be used by the Base Civil Engineering Contract Programming Section to develop cost estimates for base-level projects and provide management with a usable range of expected project costs.

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I. Introduction

Background

Each year a base-level, civil engineering organization will contract from $5 to $8 million worth of construction with civilian contractors. These projects are typically set aside for small businesses and are competitively bid. When the bids are opened, the contractors' bids are compared to the government cost estimate. If the bids differ from the government estimate by more than 20 percent, plus or minus, the Federal Acquisition Regulations (FAR) require civil engineering and the contracting officer to determine whether or not the bids are fair and reasonable (6:14).

The acceptability of a low bid may ultimately depend upon the need for a project, the desires of a commander, or some other subjective engineering judgement. When the low bid for a project falls outside the pre-determined, allowable variance from the government estimate, the deviation may be difficult to justify to a contracting officer.

General Issue

The government cost estimate is an important element in determining the acceptability of a low bid. Cost estimating itself is "the analytical process of determining the costs of material, labor, and other components necessary to accomplish project work" (17:60) and is considered "a key factor contributing to the success or failure of construction projects" (13:19).

The problem of significant differences between the bid prices and the government estimates has been a dilemma for some time. This difficulty prompted creation of the Office, Secretary of Defense Cost Analysis Improvement Group in 1973, by then Secretary of Defense, Melvin Laird to help validate government estimates (7:3). A 1984 study conducted by the Air Force indicated that more than 50 percent of the government estimates reviewed were outside the FAR criteria (8:2).

Concern for Accurate Bids

With such a large percentage of bids outside the FAR's acceptable bid range, the Base Civil Engineer must be reasonably assured he/she is receiving fair and acceptable bids for each project. High bids could reflect dollars being spent needlessly. Extremely low bids might indicate future problems should a contractor try to recoup losses with less than quality work. The Department of Defense (DOD) funding is closely scrutinized and every bid accepted by civil engineering must be defendable as being fair and reasonable.

Research Objective

The objective of this research is to develop an independent, cost-verification system that will determine a range of acceptable prices for a project estimate based on historical contractors' bids. Typically, the government estimate is a single price and does not include any expected variances from the project estimate. The proposed estimating system will provide the most likely estimator for each construction cost element, and then define the variation that can be associated with that item. By summing the items of work, a mean estimate with upper and lower limits can be calculated.

Research Hypothesis

Analyzing local cost data and developing an estimating system for that locale only can produce an individual cost model that will allow determination of a range of costs for a construction project. The identified range of costs could accurately reflect a reasonable cost for a project and provide an additional measure for allowing a low bid notwithstanding the FAR criteria.

Research Questions

To develop this hypothesis, the following research questions will be considered:

1. Does the problem of estimating still exist to the extent identified in the 1984 study?

2. What previous systems have been developed that utilized a probabilistic estimating method?

3. What historical data is available as input for a cost-estimating system?

4. How can the historical bid data be analyzed to provide an estimating system that will enable verification of bids quickly and accurately?

Limitations

This research will be limited to general building construction which will be classified as minor construction. Minor construction projects are defined as having a $200,000 Statutory Limit. Contractors' bids over $200,000 are considered non-responsive, and are not eligible for contract award. Project size will be limited to projects under 5,000 square feet and included in the small business, set-aside category by a base contracting organization. Military construction projects requiring funding by congressional action will not be included.

II. Literature Review

General Background

The complexities of the total design and construction effort for the Base Civil Engineer converge to a single element - money. Each project that is programmed for accomplishment by contract includes an estimated cost of construction on a conceptual basis. The cost estimate is used by management during the programming and design cycle to determine the priorities, budget requirements, and total scope of the construction program. When a cost estimate is presented to management, it is essential that the accuracy, range, and confidence limits of the estimate be defined (12:4).

During design, the designers, whether architectural/ engineering (A/E) firms or in-house engineers, provide estimates at various stages of design completion to ensure the project is progressing within the budget. At 100 percent design, a detailed, final-cost estimate is prepared for the contracting office enumerating the government estimate for the project. At the time of bidding, the estimate is compared to the contractors' bids for a determination of award.

Cost-Estimating Process

Different estimating techniques are used as a construction project progresses from a concept to the final design.

Various techniques are used because cost estimating plays a major role in determining the price for any project. It is the estimate that forms the basis for most decisions for proceeding with a project as designed, revising to lower costs, or adding more features if additional monies are available. A review of these methods follows.

Standardized Procedure. The creation of a cost estimate is a standardized procedure of (13:20):

1. Estimating the quantity of work elements,
2. Selecting the applicable cost from a cost-estimating guide,
3. Calculating the direct cost of each line item,
4. Making allowances for indirect costs such as overhead and profit, and
5. Summarizing the total cost for a spot estimate.

"Estimates for construction costs are used for different reasons and so are made by different methods and provide different answers" (14:8). Estimates vary from less detailed to more accurate as a project evolves from conceptual to preliminary to final design (2:177).

Conceptual Estimates. Conceptual estimates are made early in a project for an approximate cost. This type of estimate gives the owner an idea of the cost of a project without much detailed information. These estimates can be generated in several methods.

Cost per Square Foot. The most important quantity parameter in any building is the total floor area (12:62).

The total square footage of a proposed structure is multiplied by an average cost per square foot to produce the estimated cost. The cost per square foot usually includes all the features of a proposed building such as foundation, walls, heating, air-conditioning, and electrical (14:8).

Parameter Estimate. Some broad parameters relate all costs of a building to a single or few physical attributes such as number of beds in a hospital or production capacity of a chemical plant (2:186). Other important quantity parameters are building volume, perimeter, total roof area, and total wall area (12:62).

Cost Indices. Cost indices relate costs in one locale to known or estimated costs in another locale. This index could be used for inflation or for demographic situations (2:179).

Cost-Capacity Relationships. Cost-capacity relationships relate costs to changes in scope, size or capacity of similar projects. For projects such as a steel mill (for tons of steel produced) or for a refinery (for gallons of gasoline produced), an empirically derived exponent is used to prorate a new cost from the known cost of an existing facility of different size or capacity (2:181; 9:299).

Detailed Estimates. As the project is designed, the estimates become more detailed. This involves a quantity takeoff of all materials required as identified in the standardized procedure. These quantities are multiplied by the cost of the material and the cost of labor. A careful takeoff will minimize errors in this procedure (14:10). The larger the number of elements used in estimating a project, the more accurate the total estimate should be (12:43).

Costs for a detailed estimate will usually be classified as either direct or indirect. Direct costs are associated with the ability of the facility to function. Indirect or overhead costs are associated with the construction, but leave no visible product justifying the cost (9:298).

Cost-Estimating Philosophy

A difference in philosophy of the estimating process exists between the government and the contractor. Contractors' bids are based as closely as possible on the actual cost of construction. These estimates reflect material costs on specific items proposed for use, the man-hours calculated for installation, and the profit margin included by the firm. For the contractor,

> Proper evaluation of labor productivity, effects of local practices, market competitiveness, weather conditions, and completeness of plans and specifications are extremely important in the preparation of detailed estimates (2:187).

Government estimates are fair-cost estimates representing the professional engineer's or architect's assessment of the equitable cost of the project (2:128). The line items of these estimates reflect a broader estimate since specific items for installation are unknown. Installation costs are usually figured on a per unit basis in lieu of actual man-hours.

Both fair-cost estimates and contractors' bids are usually detailed cost estimates. The primary difference between fair-cost estimates as used by Air Force Engineers, and contractors' bid estimates is the number of line items used in preparing an estimate. Generally, the contractor's estimate will contain more information than the government estimate. A contractor's bid will include field overhead, equipment rental, and subcontractor quotes not detailed by a fair-cost estimate (2:187).

Historical Cost-Estimating Data

Historical data has been a primary source for developing cost-estimating techniques since 1927 (20:153). Building Construction Cost Data, published by R. S. Means Company, is a well-known example of a system that utilizes historical data. Costs from construction projects around the United States are categorized into very detailed, specific, work elements. Each work element is divided into labor, material, subcontract price, and total cost. Various factors, such as regional labor rates, geographical area, and cost indexes are calculated to localize data for estimating purposes.

"The actual estimate put together by a contractor is a combination of several items: materials, labor, overhead and profit" (14:11). The material portion is the simplest to estimate. A quantity takeoff will provide the amount of material required to construct the project and allow for waste. Labor is the hardest to calculate due to various factors that can affect productivity. Overhead costs can vary widely, whether fixed or variable. Fixed overhead costs are those costs associated with doing business such as utility fees or office space. Variable overhead costs depend on the project and include such items as site utilities, security, job office, insurance, and bonds.

Bidders' profit margins may also vary depending on the competitiveness of work, the economic climate, and the time of year (14:12-13).

Variability in Cost Estimating

"The cost estimate of a construction project as conventionally produced is a deterministic mathematical model of that project" (18:65).

> As usually prepared, cost estimates are point estimates, i.e., single-valued estimates based on the most likely values of the cost elements. These point estimates may or may not accurately depict the expected value of the estimate, and they certainly do not indicate the possible range of values an estimate may assume (9:300).

The difference in philosophy between fair-cost estimating and bidding can provide many areas where variations between the government estimate and the contractor's bid can be accentuated. These uncertainties point out the possibility of variation in any estimate produced, whether by a construction contractor or a design firm.

Construction Variables. Means Assemblies Cost Data indicates several construction-related factors that can affect the cost of projects including the quality of work specified, overtime required to complete a project by a certain deadline, productivity rates of various trades, the size of the project, and the project location. Other factors such as seasons of the year, union restrictions, building-code requirements, and labor and material availability can also affect the final price.

> Such factors are difficult to evaluate and cannot be predicted on the basis of the job's location in a particular section of the country. Thus, there may be a significant, but unavoidable cost variation where these factors are concerned (16:ii).

Uncertainties. Uncertainties can be classified into three areas: market prices for materials and labor rates, quantities of materials and labor productivity, and total quantity of an item. Wage and price uncertainty comes from our free enterprise economic system. Supply and demand influence the price of goods. Availability and construction activity in an area can affect the selling price. Inflation causes variance in prices. Since construction projects are not identical, the amount of material to do a specific task and the productivity rate may vary. The amount of material and labor required to install an item may vary from job to job and season to season. Even the total quantity takeoff may have uncertainty associated with it. Depending on the experience of the estimator, the completeness of the plans, or the time allowed for the estimate, the final quantity could vary substantially (1:17-20).

Statistical Concepts in Cost Estimating

Even though cost-estimating reference books have implicitly agreed to variation, not much has been written to formalize the ways of dealing with cost-data uncertainties and variations (1,3,9,18). Ranges of values have been proposed for some work elements, but judgement by the designer is still required to select where in the range the expected cost of an item lies. He then uses that single value as his estimate and does not indicate any degree of uncertainty (1:8).

Researchers have found that cost advice given to clients can be improved by studying the variability using statistical techniques. These methods provide a way that the uncertainty and variability of cost data can be quantified and then reduced. Cost estimators who are expected to give accurate advice to clients without the quality of data needed to provide it will be benefitted (3:1). Several methods are available for studying variability and statistically analyzing cost data.

Measuring Variability. "The statistical concept of variability is subtle, but it is essential to an understanding of the application of statistical methods to building price data" (3:5). Contractors' estimates will vary on any particular project, as will a fair-cost estimate from the government. When pricing guides are used to determine an estimate, the concept of variability is presumably omitted. However, it is actually concealed as it is hidden in the line item cost. The variability of the unit price is ignored by the estimator who assumes the prices for material and labor to be fixed (3:6). The variability of cost estimates can be handled in several ways including:

Range. The range is the difference between the highest and lowest figures. Although it is easy to calculate, the range is sensitive to data out-of-scale with the rest of the data. It can be used to define the upper and lower cost limits for an item.

Mean Deviation. The mean deviation is the arithmetic mean of the deviation when all deviations above and below the mean are treated as absolute or positive numbers. The more the deviation from the mean, the greater the average will be. The mean deviation can be used to gain insight into the amount of variation of an item.

Standard Deviation. The standard deviation is a measure of variance derived from the square root of the sum of the squares of the deviations from the mean. This measure of population variation allows for usage in other statistical methods that cannot use absolute values. It is used to indicate the amount of dispersion around the mean value.

Coefficient of Variation. The coefficient of variation (CV) is the standard deviation divided by the arithmetic mean and expressed as a percentage. It is used as a measure of the variability of a population. The smaller the CV, the less the variation in the population (3:11-16).

Statistical Methods. Statistically, the variability and uncertainty of cost elements measured can be used with several methods to prepare range estimates.

Direct Analytical Techniques. Assuming a continuous probability density function, the expected value, E(X), of an individual cost element is

$$E(X) = \int_{-\infty}^{\infty} x\, f(x)\, dx \tag{1}$$

where x is the random variable and f(x) is the probability density function.

The cost of a facility, Y, is the sum of the expected individual values, given as:

$$E(Y) = E(X_1) + E(X_2) \tag{2}$$

The variance, σ^2, associated with the cost is:

$$\sigma_Y^2 = \sigma_1^2 + \sigma_2^2 + 2\sigma_{1,2} \tag{3}$$

Note, when cost elements X_1, and X_2 are independent:

$$\sigma_{1,2} = 0 \tag{4}$$

However, in construction cost estimating, independence is not strictly true. Many construction elements are dependent on each other such as concrete and reinforcing steel. Correlation between individual items does not affect the total mean, but it does affect the total variance. Alberts feels the effect is minimal and for ease of calculations, independence can be assumed between the various cost components (1:14).

Frequency Distributions. Distributions of cost elements must be related to some formal statistical distribution for analysis. Since cost data can take on any real value, the distribution must be continuous rather than discrete (12:43).

The Central Limit Theorem states that the sum of the cost elements will tend to be normally distributed, regardless of the probability frequency distributions of the individual elements under general conditions. If the general assumptions of the Central Limit Theorem are satisfied, the final cost estimate of a building can be predicted with the mean, variance, and normal probability density function (9:301).

Theoretically, normal distributions for cost elements are approached more closely when using logarithms of the values instead of the values themselves. When a series of values is limited on one end, the frequency distribution will be more or less asymmetrical. Cost data is limited by zero on the low end (12:44).

Because of the complexity of the logarithmic calculations necessary to compute total estimate accuracy, it is more advantageous to use the standard normal distributions instead of the logarithmic normal. This is a valid substitution, provided the range or error can be limited to 40 percent or less (12:47).

> Ferenz has also endorsed this substitution of the standard normal distribution; he states, 'For practical purposes, however, logarithms are seldom

> necessary. If your information is precise enough, the deviation will be small, and if the information is very rough, using logarithms won't improve the precision significantly anyway' (12:47).

When the following criteria are met, the assumption of a normal distribution for the total cost distribution should be very satisfactory (1:58):

1. A sufficient number of variables are available in the data base, at least 15.

2. No one variable is dominant, that is, the variance of any one element is less than one-quarter of the total variance.

3. Individual component distributions are not strongly skewed.

4. Coefficients of variance of the total cost are relatively small, less than 0.25 or 25 percent.

5. None of the dominant variables are highly correlated.

Simulation Methods. Simulation is another statistical technique that provides for the experimental sampling of random cost elements which can be used to calculate a sample total cost for a project. Monte Carlo Methods require specifying the probability function for each cost element. Once specified, each cost element can be repeatedly sampled using a random number generator. The total cost of a building can be calculated for the random values of each cost element. Plotting the values for the total cost into a histogram will yield an approximate probability-distribution function for the total cost (9:303). An estimator can approximate, through a series of experiments, the total cost of a building when the frequency distributions of the component costs are known (1:13).

Regression Analysis. Regression analysis is a least squares analysis that has been used to identify a relationship between one or more independent variables and a dependent variable (10:76). Regression has a place for application in construction estimating. The variables can be described by factors representing their contribution in usable terms. These factors can then form an estimating formula. Unfortunately, some researchers have used the results in misleading ways and inferred too much from too little data. Any variable can be included in the list of factors, so a variable could be included whose apparent effect contradicts common sense. It is the responsibility of the researcher to ensure the best fit straight line represents the data in the sample correctly (3:20,139).

Time-Series Forecasting. Time-series forecasting uses historical data to project costs to future time periods. This method analyzes the pattern of the time series and projects a pattern to the future. Similar to a regression model, the independent variable is a specific time period (10:76,79).

Exponential Smoothing. Exponential smoothing is a forecasting method that projects costs to the next time period by modifying the last period costs by the forecast error. A smoothing constant, α, is used to determine the amount of forecast error that is carried over from period to period in the estimate (10:76,97).

Air Force Cost-Estimating Programs

Cost estimating is such a vital need in the Air Force that the Air Force Engineering and Services Center (AFESC) Directorate of Construction Cost Management has been developing a computerized cost-estimating system since 1981. It is to provide the Air Force with an independent, in-house ability to estimate and analyze construction costs for the Military Construction Program (MCP). The purpose of the Construction Cost Management Analysis System (CCMAS) is to assist in accomplishing an accurate, independent, cost analysis (4:1).

CCMAS. CCMAS is more than just a cost-estimating system. It is an entire estimating and analysis methodology with various manual and automated tools (4:1). The methodology, as explained by Thomas Burns, Chief of the Cost Management Directorate, is straightforward. The problem is defined, data is gathered, assumptions are made, and the analysis is accomplished. After the analysis, the results are briefed and discussed with management, and the estimate revised as necessary.

This system can produce several types of estimates including direct costs, life-cycle costs, and modifier costs.

Direct costs are historical construction costs used to develop cost-estimating relationships for various building parameters that can be used to forecast future costs. Life-cycle costs sum the cost of an item over its expected life span. It includes recurring maintenance, component replacement, and physical damage repair. Modifiers adjust the direct costs to provide a specific final estimate by adjusting for several factors such as contractors' overhead and profit, construction methods for different regions, location factors for specific geographical labor rates and climates, and contract management costs for the government and A/E design fees.

According to designer information on this cost-estimating system, the administrative module has a range of 5,000 to 500,000 square feet (5:9). This makes CCMAS appropriate for the MCP project estimates. It was noted that any building size less than 7,500 square feet must be carefully checked by the estimator (5:2-11). The size limitations make this system undesirable for base-level projects less than 5000 square feet.

Base-Level Estimating. Captain Stark's 1986 master's thesis indicates most base-level engineering staffs utilize the Means construction cost-data pricing guides for cost estimating (19:45). Means Building Construction Cost Data, 1988, indicates that project size is aimed primarily at industrial and commercial new construction projects costing more than $500,000 (15:iii). Material prices given are usually large-purchase quantities. Means Assemblies Cost Data, 1988, is primarily for projects over $400,000. Both manuals indicate "with reasonable exercise of judgment, the figures can be used for any building work" (16:v;15:iii).

Summary

Cost estimating is a very important part of the total construction project. Many times, the final decision regarding construction of a project will hinge on the final cost estimate. Most estimates are figured on a single point estimate that hides the randomness or uncertainty inherent in the procedure of cost-estimating. Several probabilistic methods are available which could help an estimator determine an acceptable range of costs for a project.

III. Methodology

The purpose of this chapter is to describe the methodology used to test the research hypothesis and to define the development of the research objective. The basic outline for this methodology is to confirm the need, collect the data, analyze the data, and test the concept. The results for each step are identified in Chapter IV.

Confirmation of Need

The problem of differences between the governments' estimates and contractors' bids has been an issue since 1973. To determine if any improvement has been made, a random sample of awarded projects for two fiscal years was taken and listed by project number, description, government estimate, and award amount.

The following HQ USAF/ACM sampling formula was utilized to determine sample size:

$$n = \frac{N\ (z^2) \times p\ (1-p)}{(N-1)\ (d^2) + (z^2) \times p(1-p)} \qquad (5)$$

where

n = sample size
N = population size
p = maximum sample size factor (.50)
d = desired tolerance (.05)
z = factor of assurance (1.96 for 95% confidence level) (11:11-14).

The percentage of deviation from the government estimate was calculated for each project in the sample. A statistical test was made of the sampled proportion of projects outside the allowed variance at 95 percent reliability to determine if the proportion had changed from the 50 percent level measured in 1984.

Collect Project Data

The research hypothesis is based on the idea that local data collected for cost estimating is best for that locale only. "To be useful, all of this information must of course be local" (14:9). "Local conditions, such as material prices, wage rates, labor productivity, and anticipated competition, are important in achieving a reasonable estimate for the area" (2:129). Trying to localize historical data generalized from a larger geographical area by using various factors can introduce error into the final estimate.

For purposes of this study, Davis-Monthan Air Force Base, Tucson, Arizona was selected as the test locale. Projects from base civil engineering contract information were analyzed. The researcher's firsthand knowledge of the projects and the availability of the required data allowed an accurate classification of the identified work elements. The projects selected were minor construction and had sufficient, separate line items that provided a good cross section of construction work. The costs and scope of work for the selected projects were typical for base-level construction. The material gathered included the bid results, the government estimate (AF Form 3052, Construction Cost Estimate Breakdown), the programming project data sheet (DD Form

1391, Military Construction Project Data), and the progress report (AF Form 3064, Contract Progress Report) or schedule (AF Form 3065, Contract Progress Schedule).

The bid results, government estimates, and programming data sheets were used to obtain project costs and scope of work. The progress reports or schedules were used to determine the proportion of work. The progress report identifies the major elements of work and an appropriate percentage of that element in relation to the entire project.

The contractor must submit a contract progress schedule to indicate the flow of construction. The percentages on the schedule, according to the AF Form 3065, are to reflect the contractor's reasonable estimate of each major element of work in the contract. For example, a possible work element could be concrete or electrical and be identified as 10 or 15 percent of the project.

Square Footage Estimates. The elements of work for the analysis were categorized according to the 16 major divisions of the Construction Specification Institute (CSI) as listed in Appendix A. The CSI system was selected because of its generalized use in the construction industry and the ease of coding work elements for analysis and comparison with other pricing systems. Divisions 11, Equipment, and 12, Furnishings, were not used because these items are generally beyond the scope of base-level construction projects. Division 1, General Requirements, is spread throughout the various cost elements as these items cannot be listed separately on the contract progress schedule.

The historical data collected was separated by project into the applicable divisions. The building square footage was obtained from the design documents, programming documents (DD Form 1391), or the government estimate. Another classification was assigned depending upon the building usage as being administrative or warehouse/maintenance.

The unit cost for a work element was calculated by multiplying the contract price by the estimated percentages of work as identified on the contractor's progress report. The estimated cost of the work element was then divided by the unit measure of construction. For example, if the contract cost was $100,000 and the estimated percentage for the concrete work was 10 percent, the estimated cost of the concrete work would be $100,000 times 10 percent or $10,000. Similarly, if the estimated percentage for the electrical work was 15 percent, the estimated cost would be $100,000 times 15 percent or $15,000. If the building was 2,000 square feet, then the unit cost for concrete would be $10,000 divided by 2,000 square feet or $5.00 per square foot. The electrical unit cost would be $15,000 divided by 2,000 square feet or $7.50 per square foot.

An analysis of each identified line item of work was made to determine the mean or average cost per unit of measure and the standard deviation from the mean. The means and standard deviations were calculated from the data for all projects, administrative facilities only, and warehouse/maintenance facilities only.

Analyze Data

Estimating Procedure. After the square footage costs had been determined, a project cost estimate was calculated by identifying the elements of work and the building parameters, usually square footage. Multiplying the square footage by the mean cost for the building's total construction cost elements indicated the average cost for that project. The confidence interval was identified by the formula:

$$\text{Cost} = F \times [M \pm (t \times \sigma) / n^{1/2}] \qquad (6)$$

where

F = square footage of facility
M = average cost per square foot
t = Student's t-distribution for 95% confidence interval
σ = estimated population standard deviation
n = number of projects in data base (3:67)

With the small data base, Student's t-distribution was used instead of the standard normal curve.

An estimate for the projects in the data base was calculated and the range of a fair-cost estimate determined to test the accuracy of this concept. The actual bid price was then compared to the estimated range to determine if the low bid was included in the calculated range.

Comparison of Statistical Methods. Several different techniques were examined to determine the estimate and define the confidence interval. These methods included: mean square foot cost, summation of the mean square foot cost for each division of work, summation of the median square foot cost for each division of work, simulation, multiple regression, and time-series forecasting.

The various techniques were then compared to find the method that provided the smallest range of acceptable values (which indicated the least range variance) and included the low bid in the estimated range. The goal was for the range to be less than 20 percent, thus exceeding the FAR requirements.

Test Program

A final test was performed on a new project. A fair-cost estimate and range were calculated using the average building costs determined by the research. The low bid was compared to the range of estimated values to verify the acceptability of the contractor's low bid.

Summary

These methods of statistical estimating will determine if a more objective basis can be provided for accepting or rejecting contractors' bids. These estimates are based on local, historical records and will demonstrate a range of values for bid acceptance that will have more meaning than a set percentage identified by the Federal Acquisition Regulations.

IV. Results and Analysis

Overview

The purpose of this chapter is to enumerate the results of this research and answer the research questions posed to develop a cost-estimating system for verifying bid results. This chapter will confirm the need, display the data, analyze the data, compare the results, and test the results.

Confirmation of Need

Tactical Air Command (TAC) was used as a representative command to determine if the total construction program bid variance as identified in 1984 still exists. If the problem has been reduced to a reasonable level, TAC cost-estimating methods need to be conveyed Air Force wide.

A complete listing of all construction projects awarded in the command during Fiscal Year (FY) 86 and FY87 was obtained from the TAC Contract Management Section (DEEC) to verify the current percentage of TAC projects outside the FAR limits. This listing, from the Civil Engineering Contract Reporting System (CECORS), tabulated all TAC bases and identified the contract projects by project number, description, fiscal year, method of design, award date, estimated amount, and award amount. It was assumed in evaluating the listing that the estimated cost in CECORS reflected the government estimate and the award amount listed the low bid.

There were 688 projects for FY86 and 701 for FY87. A random sample, as determined by Eq (5), of approximately 250 projects was taken for each year. For FY86, 117 of the 244 projects sampled, or 48.1 percent, were outside the FAR criteria. For FY87, 126 of the 247 sampled projects, or 51.2 percent, were outside the FAR criteria.

A problem still exists. Statistically, from the samples taken, TAC continues to have a problem with cost estimating. The figures indicate that Base Civil Engineers in TAC must defend approximately half of the projects sent to contracting.

Collect Area Data

Davis-Monthan AFB Commander's Update Reports were reviewed to identify minor construction projects under 5000 square feet that would represent a broad range of construction elements for analysis. After a review of all the reports, thirteen minor construction projects, listed in Appendix B, were available for analysis that fit the limitations and included sufficient elements for this research. These projects were bid during the period FY84 to FY87. Construction cost details were requested and collected for analysis.

Because of the $200,000 Statutory Limit on minor construction, very few projects were available for analysis. Many new construction projects were part of the Military Construction Program (MCP) and were beyond the scope of this research. These larger projects were tracked and independently estimated by Air Force Engineering and Services Center Construction Cost Management Directorate.

Research Data Base

Each project selected was reviewed to determine the percentage of work identified on the contractor's progress report. The percentages were recorded under the various divisions of work identified on the thesis worksheet shown in Appendix C. The total percentages were then converted to costs per square foot for each division. The resulting costs are shown in Table 1. The variances associated with the construction costs are noticeable. For two projects with similar total costs per square foot, the electrical costs varied from $5.41 per square foot for Project DMT 830300 to $9.76 per square foot for Project DMT 860500.

Not all projects contained all divisions of work. For example, a project that was constructed with a prefabricated building did not use masonry or metals. Common elements to all projects were concrete, finishes, plumbing, electrical, and site work. Doors and windows, which would be considered common for most projects, were too small an item on two of the projects to determine a square footage cost from the contractor's percentages. The average percentage for this division was 5 percent, compared to electrical at 15 percent, and concrete at 10 percent. The thirteen projects included

Table 1. Research Cost per Square Foot by Project and Division

Project No	850100	790052	860074	860500	820300	860048	860068	830300	860096	790136	820129	860039	850034
Total Cost/SF	117.5	49.53	103.12	88.74	86.00	45.93	68.72	69.73	78.53	54.32	70.48	96.66	61.70
Sq Foot	600	840	1920	2016	2080	2100	2400	2438	2496	2688	2800	3000	3225
FY	86	85	86	86	87	86	86	84	86	84	84	87	86
Bldg Code	W/M	Adm	Adm	Adm	Adm	W/M	Adm	Adm	Adm	W/M	Adm	Adm	W/M
Cost per Square Foot by CSI Division													
Concrete	11.16	9.90	7.73	11.54	6.28	4.59	4.81	8.36	5.89	5.43	6.20	11.79	5.68
Masonry		7.43			6.86	6.52	6.87	9.06				11.98	
Metals					10.15		8.24	9.06				7.25	
Wood & Plastic	5.40	7.43	5.67	2.29	4.13	3.90		2.79	4.71		.42	2.22	1.36
Thermal Protct		5.45	.52	2.00	6.62	1.74	4.12	3.49	.39	1.09	.85	3.57	
Doors & Window	4.23		3.61	4.43	6.28	2.75		4.88	2.36	1.63	3.94	10.63	1.91
Finishes	6.93	3.96	10.83	11.91	13.67	5.74	8.93	6.97	8.64	6.25	7.82	11.70	2.65
Specialities			1.55			.64			1.18	.54	.49	.10	
Pre-Fab Bldg	21.73		18.56	22.85					15.71	6.52	10.36		9.01
Plumbing	12.33	4.95	5.16	5.64	7.48	5.97	2.06	4.87	7.85	9.23	7.68	4.83	9.75
Refrig		3.96		5.00	8.17						11.14	5.22	14.80
Air Distrib	14.80		12.38			1.79	10.99	4.88	7.85	9.51			
Electrical	29.96	3.96	19.08	9.76	5.41	2.52	15.12	8.36	10.21	11.68	10.71	15.85	10.55
Site Work	10.92	2.47	18.04	13.31	10.92	9.73	4.81	6.97	17.27	2.44	10.99	11.8	5.98

nine administrative classifications and four warehouse/ maintenance classifications. The definition for administrative-type facilities was very broad and included any building not used for storage purposes.

The frequencies of the square foot costs for several of the common divisions were measured and histograms constructed to try to identify any distributions of the data. The histograms are shown in Appendix D.

The frequency histograms indicated most of the distributions were slightly skewed to the right. The median cost was always to the left of the mean cost. The difference between the lower quartile and the median was less than the upper quartile and median. This indicates a faster rise to the median and then a tailing off to the maximum costs, again, a distribution skewed to the right.

The administrative facility test group frequencies appeared to be less skewed, tending more towards a normal distribution. Approximately one-sixth of the projects should be outside plus or minus one standard deviation (plus or minus) to give a hint to a normal distribution. The small data base of projects made it difficult to specify any kind of distribution for the work divisions.

Research Data Analysis

The research data base was analyzed by the different methods to determine which technique would provide the best indicator of least range variance and meet the FAR established goal of 20 percent. The methods were examined for test groupings consisting of all projects, administrative facilities, and warehouse/maintenance facilities.

Valid Test Groupings. The range variances for the warehouse/maintenance facilities approached 70 percent early in the analysis. The time-series forecast had a range variance of over 60 percent, which was too great for further consideration in this analysis. A determination was made that this test group and method contained too few data points. Information was available for four warehouse/maintenance projects and four time periods. These few points caused too much variation to be considered any further. The research was then limited to the other two test groups.

Mean Square Foot Cost. The mean square foot cost calculated from the data base is shown in Table 2. Using these average square footage costs, a range of estimated values was calculated using Eq (6).

Table 2. Mean Square Footage Costs for Research Test Groups

Test Group	Average	Std Dev	CV(%)
All Projects	76.23	21.52	28.22
Administrative	79.06	16.47	20.83

The low bid prices were compared to the estimated range to determine if the range included the low bid amount. Summaries of these results are shown in Tables 3 and 4.

The range variance for this method provided a smaller range than the FAR requirements, but the low bid was within the range less than one-half of the time for all projects and two-thirds of the time for the administrative facilities. Projects with either a very high or very low square footage cost were not included in the calculated range. Statistically, a coefficient of variation (CV) of 20 or 28 percent indicates the research population variation is within the range of the national averages listed in the Means construction cost guides (15:362).

Summation of Average Division Costs. The average cost and standard deviation for each identified division was calculated. The standard deviation was corrected by dividing the sample standard deviation by n-1, where n is the number of projects, to provide an unbiased estimator for the population. Table 5 lists the averages for all thirteen projects. Table 6 summarizes the means for the administrative projects.

Table 3. Summary of Estimated Ranges by Mean Square Footage Method for All Projects

Proj No	Sq Ft	Gov Est	Gov Est Var	Low Bid	Mean Est	Mean Var	Range High	Range Low	Range Var	Low Bid in Range
85-0100	600	57100	23.5%	70500	45738	54.1%	53541	37935	17.1%	No
79-0052	840	48200	13.7%	41601	64033	35.0%	74958	53109	17.1%	No
86-0074	1920	194204	2.0%	198000	146362	35.3%	171332	121391	17.1%	No
86-0500	2016	143478	24.7%	178900	153680	16.4%	179899	127461	17.1%	Yes
82-0300	2080	206090	13.2%	178900	158558	12.8%	185610	131507	17.1%	Yes
86-0048	2100	46436	107.7%	96457	160083	39.7%	187395	132771	17.1%	No
86-0068	2400	187399	12.0%	164919	182952	9.9%	214165	151739	17.1%	Yes
83-0300	2438	198871	14.5%	169995	185849	8.5%	217556	154141	17.1%	Yes
86-0096	2496	197347	.7%	196000	190270	3.0%	222732	157808	17.1%	Yes
79-0136	2688	133800	9.1%	146000	204906	28.7%	239865	169947	17.1%	No
82-0129	2800	198700	.7%	197350	213444	7.5%	249859	177029	17.1%	Yes
86-0039	3000	284602	5.1%	298975	228690	30.7%	267707	189673	17.1%	No
85-0034	3225	196260	1.4%	198976	245842	19.1%	287785	203899	17.1%	No

Gov Est Variance		Research Est Variance		Range Variance		Percent in Range
Average	17.6%	Average	23.1%	Average	17.1%	46%
Std Dev	27.2%	Std Dev	14.7%	Std Dev	0 %	

Table 4. Summary of Estimated Ranges by Mean Square Footage Method for Administrative Projects

Proj No	Sq Ft	Gov Est	Gov Est Var	Low Bid	Mean Est	Mean Var	Range High	Range Low	Range Var	Low Bid in Range
79-0052	840	48200	13.7%	41601	66410	37.4%	77045	55776	16.0%	No
86-0074	1920	194204	2.0%	198000	151795	30.4%	176102	127488	16.0%	No
86-0500	2016	143478	24.7%	178900	159385	12.2%	184907	133863	16.0%	Yes
82-0300	2080	206090	13.2%	178900	164445	8.8%	190777	138112	16.0%	Yes
86-0068	2400	187399	12.0%	164919	189744	13.1%	220128	159360	16.0%	Yes
83-0300	2438	198871	14.5%	169995	192748	11.8%	223613	161883	16.0%	Yes
86-0096	2496	197347	.7%	196000	197334	.7%	228933	165735	16.0%	Yes
82-0129	2800	198700	.7%	197350	221368	10.8%	256816	185920	16.0%	Yes
86-0039	3000	284602	5.1%	298975	237180	26.1%	275160	199200	16.0%	No
	Gov Est Variance			Research Est Variance			Range Variance			Percent
	Average		9.6%	Average		16.8%	Average		16.0%	in Range
	Std Dev		7.6%	Std Dev		11.1%	Std Dev		0 %	67%

Table 5. Division Average Square Foot Costs for All Projects

Division	Average	Std Dev	C.V.(%)
Concrete	7.64	2.64	34.51
Masonry	8.12	2.10	25.81
Metals	8.68	1.23	14.19
Wood & Plastics	3.67	2.08	56.68
Thermal Protect	2.71	2.09	77.18
Doors & Windows	4.24	2.53	59.62
Finishes	8.15	3.23	40.52
Specialties	.75	.52	69.82
Pre-Fab Bldg	14.96	6.45	43.09
Plumbing	6.75	2.67	39.57
Refrigeration	8.05	4.22	52.47
Air Distrib	8.89	4.46	50.22
Electrical	11.78	7.19	61.00
Site Work	9.67	4.99	51.65

Table 6. Division Average Square Foot Costs for Administrative Facilities

Division	Average	Std Dev	C.V.(%)
Concrete	8.06	2.54	31.50
Masonry	8.44	2.17	25.75
Metals	8.68	1.23	14.19
Wood & Plastics	3.71	2.23	60.11
Thermal Protect	3.00	2.22	74.05
Doors & Windows	5.16	2.69	52.18
Finishes	9.38	2.97	31.68
Specialties	.83	.66	78.99
Pre-Fab Bldg	16.87	5.24	31.06
Plumbing	5.61	1.84	32.85
Refrigeration	6.70	2.94	43.82
Air Distrib	9.03	3.35	37.13
Electrical	10.94	4.95	45.22
Site Work	10.74	5.26	49.02

With the mean and standard deviation costs identified for each division, the data-base projects were used to calculate an estimated cost and range for each project with a 95 percent confidence interval using Eq (6). The range of estimated costs was then checked to determine if it included the low bid. The estimate and range were calculated by including only those divisions or elements of work included in the project. For example, Project DMT 860500 had eleven elements of work identified by the progress report. A sample of the cost calculations is shown in Table 7. The summaries of the ranges of estimated costs are listed is Tables 8 and 9.

The total standard deviation for any project increased approximately two times from the mean square footage cost since each division now had its variance included. The additional variance generated a wider acceptable range of estimated costs. This increased the percentage of low bids included in the estimated range to 77 percent for all projects and to 100 percent for the administrative facilities. This helped confirm the literature review indications that the more work elements available for inclusion in an estimate, the closer the estimate should be to the cost. For this research, this means a higher probability exists for including the low bid in the estimated range.

The increased variance from the additional elements of work widened the range variance from 17 percent to 28 percent

Table 7. Sample Estimated Range Calculation for DMT 86-0500

Division	M	σ
Concrete	$ 7.64	$ 2.64
Masonry		
Metals		
Wood & Plastics	3.67	2.08
Thermal Protect	2.71	2.09
Doors & Windows	4.24	2.53
Finishes	8.15	3.23
Specialties		
Pre-Fab Bldg	14.96	6.45
Plumbing	6.75	2.67
Refrigeration	8.05	4.22
Air Distrib		
Electrical	11.78	7.19
Site Work	9.67	4.99
	$ 77.63	$ 38.10

Project Sq Ft	2016
Average Cost	$ 156,507.00

Confidence Interval

	Range	Variance
High	202921	29.7%
Low	110094	-29.7%

for all projects. At the same time, the average research estimate variance dropped from 23 percent (for one element) to 20 percent (for several elements). For the administrative projects, a similar increase in range variance and decrease in estimate variance was noted.

Table 8. Summary of Estimated Ranges by Summation of Average Division Costs Method for All Projects

Proj No	Sq Ft	Gov Est	Gov Est Var	Low Bid	Mean Est	Mean Var	Range High	Range Low	Range Var	Low Bid in Range
85-0100	600	57100	23.5%	70500	45454	55.1%	58595	32313	28.9%	No
79-0052	840	48200	13.7%	41601	57185	27.3%	73252	41117	28.1%	Yes
86-0074	1920	194204	2.0%	198000	152102	30.2%	197191	107013	29.6%	No
86-0500	2016	143478	24.7%	178900	156507	14.3%	202921	110094	29.7%	Yes
82-0300	2080	206090	13.2%	178900	165287	8.2%	209251	121322	26.6%	Yes
86-0048	2100	46436	107.7%	96457	151992	36.5%	195786	108198	28.8%	No
86-0068	2400	187399	12.0%	164919	173750	5.1%	218145	129354	25.6%	Yes
83-0300	2438	198871	14.5%	169995	195777	13.2%	247661	143892	26.5%	Yes
86-0096	2496	197347	.7%	196000	197773	0.9%	256349	139118	29.4%	Yes
79-0136	2688	133800	9.1%	146000	203091	28.1%	262840	143341	29.4%	Yes
82-0129	2800	198700	.7%	197350	219471	10.1%	284821	154122	29.8%	Yes
86-0039	3000	284602	5.1%	298975	240644	24.2%	305004	176284	26.7%	Yes
85-0034	3225	196260	1.4%	198976	241617	17.6%	311784	171449	29.0%	Yes
		Gov Est Variance			Research Est Variance			Range Variance		Percent
		Average	17.5%		Average	20.8%		Average	28.3%	in Range
		Std Dev	27.2%		Std Dev	14.3%		Std Dev	1.4%	77%

Table 9. Summary of Estimated Ranges by Summation of Average Division Costs Method for Administrative Projects

Proj No	Sq Ft	Gov Est	Gov Est Var	Low Bid	Mean Est	Mean Var	Range High	Range Low	Range Var	Low Bid in Range
79-0052	840	48200	13.7%	41601	55922	25.6%	73434	38469	31.3%	Yes
86-0074	1920	194204	2.0%	198000	159978	23.8%	210086	109869	31.3%	Yes
86-0500	2016	143478	24.7%	178900	161612	10.7%	212567	110657	31.5%	Yes
82-0300	2080	206090	13.2%	178900	167252	7.0%	216891	117613	29.7%	Yes
86-0068	2400	187399	12.0%	164919	177283	7.0%	226245	128320	27.6%	Yes
83-0300	2438	198871	14.5%	169995	201712	15.7%	260673	142751	29.2%	Yes
86-0096	2496	197347	.7%	196000	207971	5.8%	273112	142751	31.3%	Yes
82-0129	2800	198700	.7%	197350	226785	13.0%	298966	154604	31.8%	Yes
86-0039	3000	284602	5.1%	298975	243719	22.7%	316825	170613	30.0%	Yes
		Gov Est Variance		Research Est Variance			Range Variance			Percent in Range
		Average	9.6%	Average		14.6%	Average		30.4%	100%
		Std Dev	7.6%	Std Dev		7.3%	Std Dev		1.3%	

Summation of Division Median Costs. A median cost and interquartile range (IQR) for all projects were calculated next. The IQR is the difference between the upper (3/4) quartile and the lower (1/4) quartile. A standard deviation for the median for each element of work was calculated by the formula:

$$\sigma = .75 \times IQR \times (n/n-1)^{1/2} \quad (3:69) \qquad (7)$$

The results for the median cost and standard deviation for all projects are shown in Table 10. Similar results for the administrative projects are shown in Table 11.

Table 10. Median Square Footage Costs for Projects in Data Base

Division	Median	IQR	Std Dev
Concrete	6.28	4.60	3.59
Masonry	7.15	2.20	1.81
Metals	8.65	1.86	1.61
Wood & Plastics	3.90	2.61	2.05
Thermal Protect	2.00	2.67	2.10
Doors & Windows	3.94	1.89	1.49
Finishes	7.82	4.98	3.89
Specialties	.59	.69	.57
Pre-Fab Bldg	15.71	11.60	9.40
Plumbing	5.97	2.56	2.00
Refrigeration	6.69	6.14	5.04
Air Distrib	9.51	6.41	5.19
Electrical	10.55	7.68	6.00
Site Work	10.92	6.53	5.10

Table 11. Median Square Footage Costs for Administrative Projects

Division	Median	IQR	Std Dev
Concrete	7.73	4.19	3.33
Masonry	7.43	2.92	2.45
Metals	8.65	1.86	1.61
Wood & Plastics	3.46	3.19	2.56
Thermal Protect	3.49	3.69	2.94
Doors & Windows	4.43	2.14	1.73
Finishes	8.93	4.50	3.58
Specialties	.83	1.07	.93
Pre-Fab Bldg	17.13	7.68	6.65
Plumbing	5.16	2.67	2.12
Refrigeration	5.22	4.17	3.50
Air Distrib	9.42	5.32	4.61
Electrical	10.21	7.68	6.11
Site Work	10.99	7.87	6.26

Calculations similar to the summation of average division costs were accomplished to determine a range of estimated costs for the two test groups. These results are shown in Tables 12 and 13.

The n/n-1 factor used in Eq (7) is the correction applied to obtain the estimated population standard deviation. As the number of projects increased, this factor had less influence on the results.

This method of estimating the population standard deviation generally produced higher figures, indicating the estimated range was greater for any project. The average range variance increased, as expected, from 28.3 percent to 30.8 percent. The variance of the research estimate from

Table 12. Summary of Estimated Ranges by Summation of Median Division Costs Method for All Projects

Proj No	Sq Ft	Gov Est	Gov Est Var	Low Bid	Median Est	Median Var	Range High	Range Low	Range Var	Low Bid in Range
85-0100	600	57100	23.5%	70500	44760	57.5%	58793	30727	31.4%	No
79-0052	840	48200	13.7%	41601	51475	19.2%	67504	35446	31.1%	Yes
86-0074	1920	194204	2.0%	198000	148205	33.6%	196204	100206	32.4%	No
86-0500	2016	143478	24.7%	178900	148740	20.3%	198286	99213	33.3%	Yes
82-0300	2080	206090	13.2%	178900	153650	16.4%	197234	110065	28.4%	Yes
86-0048	2100	46436	107.7%	96457	144123	33.1%	186990	101256	29.7%	No
86-0068	2400	187399	12.0%	164919	165240	.2%	210610	119870	27.5%	Yes
83-0300	2438	198871	14.5%	169995	186970	9.1%	238274	135666	27.4%	Yes
86-0096	2496	197347	.7%	196000	192666	1.7%	255065	130268	32.4%	Yes
79-0136	2688	133800	9.1%	146000	197004	25.9%	260867	133140	32.4%	Yes
82-0129	2800	198700	.7%	197350	208236	5.2%	277984	138488	33.5%	Yes
86-0039	3000	284602	5.1%	298975	223380	33.8%	287270	159490	28.6%	No
85-0034	3225	196260	1.4%	198976	231491	14.0%	306627	156354	32.5%	Yes

	Gov Est Variance	Research Est Variance	Range Variance	Percent in Range
Average	17.5%	20.8%	30.8%	69%
Std Dev	27.2%	15.4%	2.1%	

Table 13. Summary of Estimated Ranges by Summation of Median Division Costs Method for Administrative Projects

Proj No	Sq Ft	Gov Est	Gov Est Var	Low Bid	Median Est	Median Var	Range High	Range Low	Range Var	Low Bid in Range
79-0052	840	48200	13.7%	41601	52601	20.9%	73808	31393	40.3%	Yes
86-0074	1920	194204	2.0%	198000	157018	26.1%	217259	96776	38.4%	Yes
86-0500	2016	143478	24.7%	178900	154728	15.6%	214825	94631	38.8%	Yes
82-0300	2080	206090	13.2%	178900	157456	13.6%	215317	99595	36.7%	Yes
86-0068	2400	187399	12.0%	164919	172824	4.6%	233718	111930	35.2%	Yes
83-0300	2438	198871	14.5%	169995	194796	12.7%	264697	124896	35.9%	Yes
86-0096	2496	197347	.7%	196000	204123	4.0%	282437	125809	38.4%	Yes
82-0129	2800	198700	.7%	197350	217224	9.1%	302686	131762	39.3%	Yes
86-0039	3000	284602	5.1%	298975	229590	30.2%	315180	144000	37.3%	Yes
		Gov Est Variance			Research Est Variance		Range Variance			Percent
		Average	9.6%		Average	15.2%	Average		37.8%	in Range
		Std Dev	7.6%		Std Dev	8.6%	Std Dev		1.6%	100%

the low bid remained constant, even with the increased range variance.

The administrative test group range variance similarly increased from 30.4 percent to 37.8 percent. This was a result of the smaller data base for this group. This variance approached twice the FAR requirement and was too large to be considered an effective tool for cost verification, even though the range predicted 100 percent of the low-bid values.

Simulation. A bid simulation was run using the computer software program Interactive Statistical Programs (ISP) Version 2.1 from Lincoln System Corporation, Westford MA. This program randomly generated a division cost given the mean and standard deviation (shown in Tables 5 and 6) for all projects and for the administrative projects. Since work elements cannot be negative, an adjustment was made to any negatively produced number by replacing it with a zero. One hundred costs for each identified division of a project were generated. The division costs were summed to an estimated cost. A histogram of the results was formed using ten steps between the minimum and maximum estimates. A range with a 95 percent confidence interval was created by eliminating the three lowest and three highest generated costs. The results of the simulation are shown in Table 14 for all projects and Table 15 for the administrative projects. A sample histogram for DMT 83-0300, Construct Arts and Crafts Addition is shown in Figure 1.

Table 14. Summary of Estimated Ranges by Bid Simulation Method for All Projects

Proj No	Sq Ft	Gov Est	Gov Est Var	Low Bid	Sim Est	Sim Var	Range High	Range Low	High Var	Low Var	Low Bid in Range
85-0100	600	57100	23.5%	70500	48568	45.2%	60766	30271	25.1%	-37.7%	No
79-0052	840	48200	13.7%	41601	55821	25.5%	73955	43733	32.5%	-21.7%	No
86-0074	1920	194204	2.0%	198000	157376	25.8%	207318	107433	31.7%	-31.7%	Yes
86-0500	2016	143478	24.7%	178900	177239	.9%	195218	105321	10.1%	-40.6%	Yes
82-0300	2080	206090	13.2%	178900	176311	1.5%	208224	128441	18.1%	-27.2%	Yes
86-0048	2100	46436	107.7%	96457	169051	42.9%	194710	109179	15.2%	-35.4%	No
86-0068	2400	187399	12.0%	164919	165753	.5%	223229	127437	34.7%	-23.1%	Yes
83-0300	2438	198871	14.5%	169995	209577	18.9%	249192	150154	18.9%	-28.4%	Yes
86-0096	2496	197347	.7%	196000	192269	1.9%	261219	146303	35.9%	-23.9%	Yes
79-0136	2688	133800	9.1%	146000	190042	23.2%	267936	138113	41.0%	-27.3%	Yes
82-0129	2800	198700	.7%	197350	235363	16.2%	285866	159608	21.5%	-32.3%	Yes
86-0039	3000	284602	5.1%	298975	253675	17.9%	300973	182728	18.6%	-28.0%	Yes
85-0034	3225	196260	1.4%	198976	242289	17.9%	319987	164590	32.1%	-32.1%	Yes
		Gov Est Variance			Research Est Variance		Range Variance				Percent
		Average	17.5%		Average	18.3%	Average		25.8%	-29.9%	in Range
		Std Dev	27.2%		Std Dev	14.2%	Std Dev		9.1%	5.5%	77%

Table 15. Summary of Estimated Ranges by Bid Simulation Method for Administrative Projects

Proj No	Sq Ft	Gov Est	Gov Est Var	Low Bid	Sim Est	Sim Var	Range High	Range Low	High Var	Low Var	Low Bid in Range
79-0052	840	48200	13.7%	41601	55621	25.2%	73550	43669	33.0%	-21.4%	No
86-0074	1920	194204	2.0%	198000	171080	15.7%	195094	115048	21.2%	-37.2%	Yes
86-0500	2016	143478	24.7%	178900	168359	6.3%	199028	122355	16.0%	-37.4%	Yes
82-0300	2080	206090	13.2%	178900	161991	10.4%	210616	129574	28.5%	-20.7%	Yes
86-0068	2400	187399	12.0%	164919	189098	12.8%	220826	141506	18.0%	-32.6%	Yes
83-0300	2438	198871	14.5%	169995	196713	13.6%	255435	157564	26.7%	-23.7%	Yes
86-0096	2496	197347	.7%	196000	213055	8.0%	263836	162274	22.6%	-31.3%	Yes
82-0129	2800	198700	.7%	197350	223066	11.5%	273201	172932	28.2%	-28.4%	Yes
86-0039	3000	284602	5.1%	298975	241187	24.0%	297469	184906	24.8%	-24.2%	Yes
		Gov Est Variance		Research Est Variance			Range Variance				Percent
		Average	9.6%	Average		14.2%		Average	24.3%	-28.6%	in Range
		Std Dev	7.6%	Std Dev		6.2%		Std Dev	5.1%	6.1%	89%

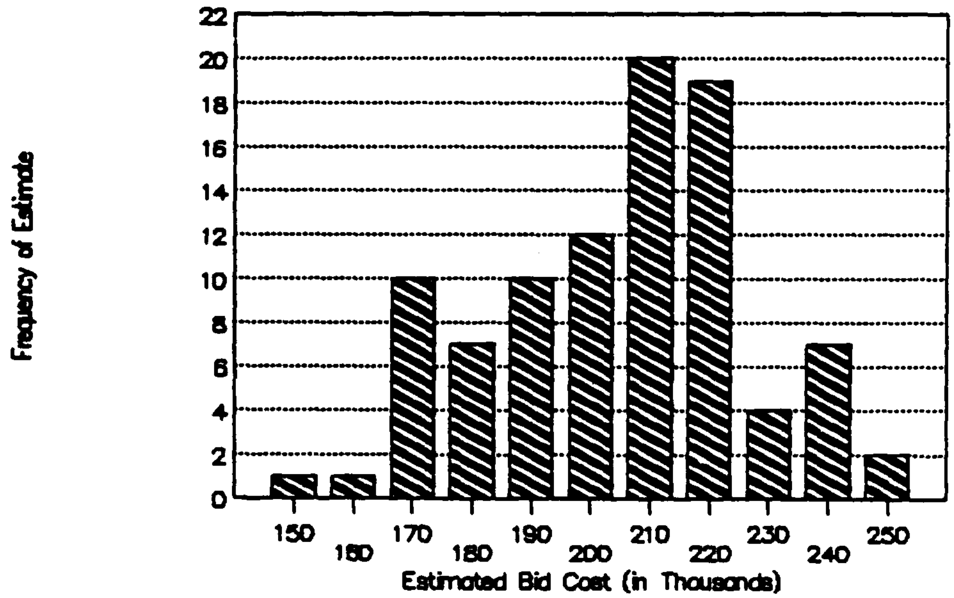

Figure 1. Sample Histogram of Simulated Bids
DMT 83-0300 Construct Arts and Crafts Facility

The frequency distribution for each element was assumed to be normal based on the literature review. The histograms tended towards normal distributions as indicated by Figure 1. The range variance noted in Table 14 was close to the summation of division averages range variance in Table 8. The average research estimate variance from the low bid was within one percent of the average variance of the government estimate. The low bid was included in the estimated range 77 percent of the time for all projects, and 89 percent for the administrative projects.

Multiple Regression. A multiple regression analysis was performed for the first test group of all projects. It was determined that too few projects were available for any meaningful regression analysis in the second test group. The results of the regression analysis are shown in Table 16.

Table 16. Summary of Estimated Ranges by Multiple Regression Method for All Projects

Proj No	Sq Ft	Gov Est	Gov Est Var	Low Bid	Reg Est	Reg Var	Range High	Range Low	Range Var	Low Bid in Range
85-0100	600	57100	23.5%	70500	45842	53.8%	53616	37836	17.0%	No
79-0052	840	48200	13.7%	41601	64178	35.2%	75062	52971	17.0%	No
86-0074	1920	194204	2.0%	198000	146693	35.0%	171570	121076	17.0%	No
86-0500	2016	143478	24.7%	178900	154028	16.1%	180149	127130	17.0%	Yes
82-0300	2080	206090	13.2%	178900	158918	12.6%	185868	131166	17.0%	Yes
86-0048	2100	46436	107.7%	96457	160446	39.9%	187655	132427	17.0%	No
86-0068	2400	187399	12.0%	164919	183366	10.1%	214463	151345	17.0%	Yes
83-0300	2438	198871	14.5%	169995	186270	8.7%	217858	153742	17.0%	Yes
86-0096	2496	197347	.7%	196000	190701	2.8%	223041	157399	17.0%	Yes
79-0136	2688	133800	9.1%	146000	205370	28.9%	240198	169507	17.0%	No
82-0129	2800	198700	.7%	197350	213927	7.7%	250206	176570	17.0%	Yes
86-0039	3000	284602	5.1%	298975	229208	30.4%	268078	189182	17.0%	No
85-0034	3225	196260	1.4%	198976	246399	19.2%	288184	203370	17.0%	No
		Gov Est Variance			Research Est Variance			Range Variance		Percent in Range
		Average	17.5%		Average	23.1%		Average	17.0%	
		Std Dev	27.2%		Std Dev	14.7%		Std Dev	0 %	46%

Common work elements that averaged more than 50 percent of the project cost were included as the independent variables, with cost per square foot as the dependent variable. The divisions included concrete, finishes, plumbing, electrical, and site work, averaging 57.5 percent for all projects.

The regression model, shown in Table 17, predicted a square footage cost that was very close to the average square foot cost in Table 2. The regression range variance was close to the average range variance for the mean square footage method shown in Table 3. The low bid was included in the estimated range 46 percent of the time, the same

Table 17. Results of Regression Analysis

Division	X Coeff	Std Err Coeff	Division Ave Cost	Weighted Cost/sf
Concrete	1.901	0.680	7.64	14.52
Finishes	2.465	0.697	8.15	20.09
Plumbing	1.055	0.716	6.75	7.12
Electrical	1.583	0.270	11.78	18.65
Site Work	1.027	0.424	9.67	9.93
Constant				5.90
	Predicted Cost/sf			76.21
Std Err of Est Cost/sf				5.556
R Squared				0.961
No. of Observations				13
Degrees of Freedom				7

percentage as the mean square footage. It also included the same projects. The correlation matrix in Table 18 verified that the assumption of the independence of elements was appropriate.

Table 18. Correlation Matrix for Regression of Work Divisions

Correlation Coeff / Prob of > Coeff under H0:Coeff=0 / NOBS = 13

	Concrete	Finishes	Plumbing	Electrical	Site Work
Concrete	1.000000 0.00000	0.266342 0.37908	0.021440 0.94458	0.386404 0.19217	0.190169 0.53375
Finishes	0.266342 0.37908	1.000000 0.00000	-0.299194 0.32068	0.133885 0.66279	0.598455 0.03071
Plumbing	0.021440 0.94458	-0.299194 0.32068	1.000000 0.00000	0.368816 0.21494	0.048214 0.87571
Electrical	0.386404 0.19217	0.133885 0.66279	0.368816 0.21494	1.000000 0.00000	0.274050 0.36490
Site Work	0.190169 0.53375	0.598455 0.03071	0.048214 0.87571	0.274050 0.36490	1.000000 0.00000

Data Analysis and Evaluation

A summary comparing the various methods examined is shown in Table 19. Calculating the average or median values and a standard deviation permitted the estimating of a range of values expected for any project. The 95 percent confidence interval provided a reliability factor to indicate the probability of a low bid falling within the estimated range. As the test group was more restricted, the percentage of occurrence of the low bid in the estimated range increased. Also, the more elements used to calculate the mean estimate, the better the calculated range became.

Table 19. Comparison of Results for Different Methods

Range Estimation Method	Average Research Estimate Variance	Average Range Variance	Percent of Projects in Estimated Range
Mean Sq Ft All Projects	23.1	17.1	46%
Mean Sq Ft Administrative	16.8	16.0	67%
Summation of Means All Projects	20.8	28.3	77%
Summation of Means Administrative	14.6	30.4	100%
Summation of Medians All Projects	20.8	30.8	69%
Summation of Medians Administrative	15.2	37.8	100%
Simulation All Projects	18.3	+25.8 to -29.9	77%
Simulation Administrative	14.2	+24.3 to -28.6	89%
Regression All Projects	23.1	17.0	46%

From the methods evaluated, the summation of division averages for the test group of administrative projects provided the best verification tool for the administrative projects. Reviewing the summation of average division costs method in Table 9, the research estimate varied from the low bid by 5.8 percent to 25.6 percent. Three of the estimates for the projects in the administrative test group were outside the FAR criteria of 20 percent. The range variance from the research estimate was 27 percent to 31 percent. This deviation was approximately 10 percent greater than allowed by FAR, but the technique provided a range of estimated costs that predicted the low bid fairly well. This estimate was based on the very loose definition of administrative facilities and was expected to provide a broader range of costs.

The projects that were consistently outside the calculated range of costs for the other methods were projects that had either very high or low square footage costs, indicating unusual structures that might require more analysis. As the projects were narrowed to administrative facilities, better estimated ranges were calculated. This demonstrates that the more uniform the projects, the more uniform the pricing. The coefficient of variation dropped from 28 to 20 percent when the administrative projects were selected from the data base, which indicated less variation in the projects.

Comparing the results of this analysis with Means Building Construction Cost Data, the median square footage costs from this research were in the upper quartile of national median costs for all cases as exhibited in Table 20.

Table 20. Square Foot Cost Comparisons of Median Costs for Administrative Facilities

	Unit Costs 1/4	Median	3/4
Total Building			
Means	$ 43.15	$ 55.40	$ 72.95
Research	69.47	78.53	90.72
Site Work			
Means	3.17	5.35	8.15
Research	6.43	10.99	14.30
Plumbing			
Means	1.65	2.48	3.54
Research	4.86	5.16	7.53
Refrigeration			
Means	3.55	4.90	7.20
Research	4.74	5.22	8.91
Electrical			
Means	3.61	5.00	6.90
Research	7.62	10.21	15.30

Test Results

The results from this analysis were tested on a new project at Davis-Monthan AFB that was bid 27 September 87. The information from this project was not included in the research data. The summation of division means was used as it provided the best indicator of costs for an administrative project. The outcome of the test program is shown in

Table 21. Based on the estimated range, the bid would be acceptable.

Table 21. Calculations for Test Project
DMT 86-0124 Construct Transient Alert Facility

Division	M	σ
Concrete	$ 8.06	$ 2.54
Masonry		
Metals		
Wood & Plastics	3.71	2.23
Thermal Protect	3.00	2.22
Doors & Windows	5.16	2.69
Finishes	9.38	2.97
Specialties	.83	.66
Pre-Fab Bldg	16.87	5.24
Plumbing	5.61	1.84
Refrigeration	6.70	2.94
Air Distrib		
Electrical	10.94	4.95
Site Work		
Cost per Sq Ft	$ 70.26	$ 28.27
Project Sq Ft	3128	
Mean Estimate	$ 219,767.00	

Confidence Interval

	Range	Variance
High	287749	30.0%
Low	151786	-30.0%

Low Bid	$ 198,000.00
Gov't Est	$ 199,231.00

Variance of Mean Estimate from Low Bid	9.9%

Problems Encountered

During the collection and tabulation of the data base, several problems were encountered that added to the uncertainty of the results.

1. The size of the data base was small. In order to take advantage of the Central Limit Theorem and a normal distribution, more projects were needed. Thirteen were available which broadened the calculated acceptable range.

2. It was often difficult to breakdown costs from the contractors' progress reports. Some divisions were together, some divisions were not enumerated, and some work elements were hidden within other work elements. For example, metal building insulation could be part of the metal building price or it could be a separate line item under thermal and moisture protection, depending on the contractor's interpretation.

3. It was assumed the contractor was reasonable in his line-item breakdown and did not try to frontload an item or overload a work element.

4. The administrative and maintenance/warehouse categories were very broad and loose in interpretation. A more uniform definition within categories could have been used if more projects were available for use in the data base.

5. Site work is a catchall type of category. Some work items could have been placed in other divisions. Exterior waterlines, for example, could have been included in the site

work division or the plumbing section. Exterior electrical work could have been in site work or electrical. This factor could raise the electrical cost if an usually high amount of site electrical was required. A contractor may also include a large percentage of the contract in site work on the progress schedule trying to obtain working capital for insurance, bonds, or mobilization.

V. Conclusions

Summary

Air Force Civil Engineering is still confronted with the problem of obtaining an acceptable fair-cost estimate for the Contracting Office. The Base Civil Engineer finds himself trying to justify nearly half of the bids as they fall outside the FAR 20 percent criteria.

Local data from previous construction can be collected and used to develop a data base of historical costs that will provide a quick analysis of acceptable prices. These figures could be used as a basis for bid acceptance of new projects. Each new project that is added to the data base should strengthen the results. As the data base grows, a more specialized breakdown of elements would provide a better range of estimates. Statistical methods can be applied to cost-estimating methods to deal with the variance and uncertainty that is faced by estimators.

These methods appear to have possibilities in assisting civil engineering with determining acceptable bid ranges prior to bid opening. The summation of the mean square foot costs for each major division of the CSI format provided an acceptable range of estimated costs. With a better defined data base, in terms of more projects and elements, it is anticipated that the range variance would start approaching the FAR criteria.

The use of bid simulation is another method that is worthy of more consideration. The simulation provided an average range variance less than the summation of the division means method because the work element variances were not cumulative for each item. With more projects in the data base, it is predicted that the frequency distribution would approach normal. With a uniform definition of facilities, the simulation should provide an excellent verification method.

One method that shows promise as a programming tool is the use of a multiple regression technique. The calculation of several weighting factors and the average price of the various elements could be used as a forecasting tool. A weighted factor could be varied by increasing or decreasing the factor by its standard error based on conceptual information. For example, if additional electrical work was anticipated, the electrical weighting factor could be increased. This would produce a range of estimates giving management a better idea of the project cost.

Published cost-estimating guides can be employed if the estimator understands the limitations and uses the information as a guide only, tempering it with judgment. The Air Force Annual Construction Pricing Guide and Cost-Estimating Programs (CCMAS) are for large projects, typically far over 5,000 square feet. The median costs in the Means guides should not be used as the Air Force expected cost since these projects fall in the upper quartile of costs.

Recommendations for Further Study

1. These statistical techniques should be verified for adequacy using local data at other bases. The data should be increased to include more projects and the results documented as to the affect on the range of costs and variance from the low bid.

2. These same techniques should be tried on maintenance and repair projects. The breakdown of unit costs would be more difficult, but could produce a verification system to help with pavement repair or replacement, interior remodeling, or rehabilitation.

3. A study should be conducted to determine if most cost-estimating problems are in the area of new construction or maintenance and repair. If it were determined that one category posed a greater problem, it could be an indication of the need for additional training for engineers.

4. The project division percentages were calculated in order to determine work-element costs. Research should be conducted to determine if the percentages could be used to help verify progress schedules. Work elements need close scrutiny to try to prevent contractors from frontloading progress schedules and collecting money prior to work accomplishment.

5. These methods could also produce program-estimating techniques that would provide better contract estimates for the Facilities Board and Major Command Headquarters. The

estimated cost could be presented with a confidence interval showing the expected range of costs.

Appendix A: Uniform Construction Index Cost Analysis Format

DIVISION 2 - SITE WORK

02200 Earthwork
02250 Soil Treatment
02550 Site Utilities
02600 Paving & Surfacing
02700 Site Improvements
02800 Landscaping

DIVISION 3 - CONCRETE

03100 Concrete Formwork
03200 Concrete Reinforcement
03300 Cast-In-Place Concrete

DIVISION 4 - MASONRY

04200 Unit Masonry

DIVISION 5 - METALS

05100 Structural Metal Framing
05200 Metal Joists
05300 Metal Decking
05400 Lightgage Metal Framing

DIVISION 6 - WOOD AND PLASTICS

06100 Rough Carpentry
06200 Finish Carpentry
06400 Architectural Woodwork

DIVISION 7 - THERMAL & MOISTURE PROTECTION

07200 Insulation
07500 Membrane Roofing
07600 Flashing & Sheet Metal
07800 Roofing Accessories

DIVISION 8 - DOORS & WINDOWS

08100 Metal Doors & Frames
08200 Wood & Plastic Doors
08400 Entrances & Storefronts
08500 Metal Windows
08600 Wood & Plastic Windows
08700 Hardware & Specialties
08800 Glazing

DIVISION 9 - FINISHES

09250 Gypsum Wallboard
09300 Tile
09500 Acoustical Treatment
09540 Ceiling Suspension Systems
09650 Resilient Flooring
09680 Carpeting
09900 Painting
09950 Wall Covering

DIVISION 10 - SPECIALTIES

10100 Chalkboards and Tackboards
10160 Toilet and Shower Partitions
10200 Louvers and Vents
10400 Identifying Devices
10800 Toilet & Bath Accessories

DIVISION 13 - SPECIAL CONSTRUCTION

13600 Prefabricated Buildings

DIVISION 15 - MECHANICAL

15400 Plumbing
15500 Fire Protection
15650 Refrigeration
15800 Air Distribution
15900 Controls & Instrumentation

DIVISION 16 - ELECTRICAL

16400 Service & Distribution
16500 Lighting
16900 Controls & Instrumentation

Appendix B: Projects in Research Data Base

DMT #	TITLE	CODE	BID DATE	SQ FEET
85-0100	Construction Addition to ECS Welding Shop	M/W	29 Sept 86	600
79-0052	Construct Ready Explosives Facility	Adm	4 Sept 84	840
86-0074	Construct GLCM Training Operations Fac.	Adm	11 Sept 86	1920
86-0500	Construct Addition to AMARC Maintenance Dock	Adm	27 Feb 86	2016
82-0300	Enclose Patio Officer's Club	Adm	24 July 86	2080
86-0048	Construct Physical Fitness Support Fac.	M/W	12 Sept 86	2100
86-0068	Alter Base Gym	Adm	29 Sept 86	2400
83-0300	Construct Arts and Crafts Facility	Adm	30 Aug 84	2438
86-0096	Construct GLCM Dorm	Adm	11 Sept 86	2496
79-0136	Construct Flammable Storage Facility	M/W	14 Mar 84	2688
82-0129	Construct Vehicle Admin/Tech Service Facility	Adm	31 Aug 84	2800
86-0039	Construct Family Hsg. Mgmt. Office	Adm	12 Feb 87	3000
85-0034	Construct Addition to Armament Shop	M/W	5 June 86	3225

Note: M/W = Maintenance/Warehouse
Adm = Administrative

Appendix C: Thesis Worksheet

PROJECT NO			
CONTRACT COST			
CLASS OF WORK		TYPE FUNDS	
YEAR			
SQUARE FOOTAGE			
BUILDING CODE			
GENERAL CODE			

Specification Section		Percent	Cost/SF
Div 3	Concrete		
Div 4	Masonry		
DIV 5	Metals		
Div 6	Wood & Plastics		
Div 7	Thermal Protect		
Div 8	Doors & Windows		
Div 9	Finishes		
Div 9680	Carpeting		
Div 10	Specialties		
Div 13	Prefabricated Bldg		
Div 15400	Plumbing		
Div 15500	Fire Protect		
Div 15650	Refrigeration		
Div 15800	Air Distrib		
Div 16050	Electrital		
Div 16720	Fire Systems		

Site Work		
Square Yards		

Appendix D: Comparison of Unit Price Histograms for Selected Work Divisions

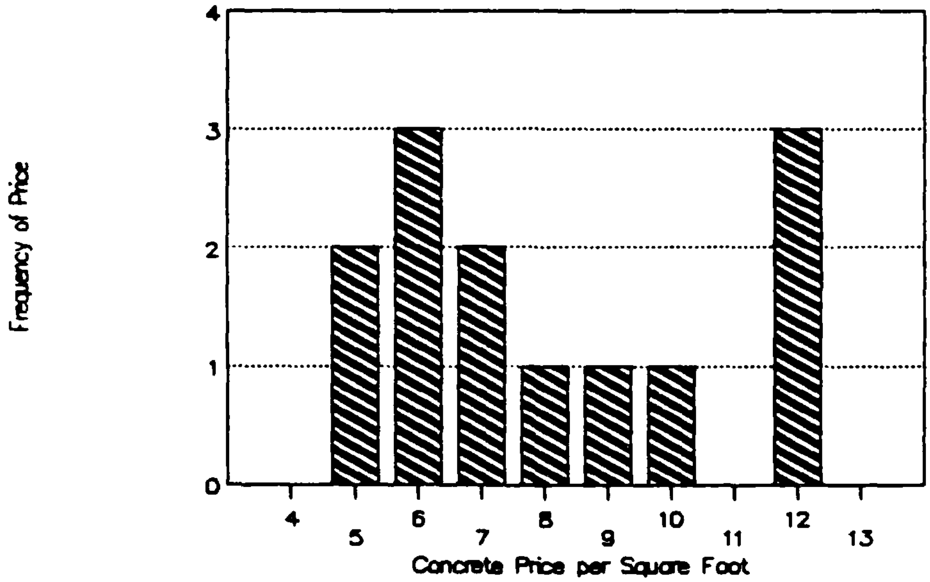

Figure 2. Frequency of Concrete Square Foot Costs for All Facilities

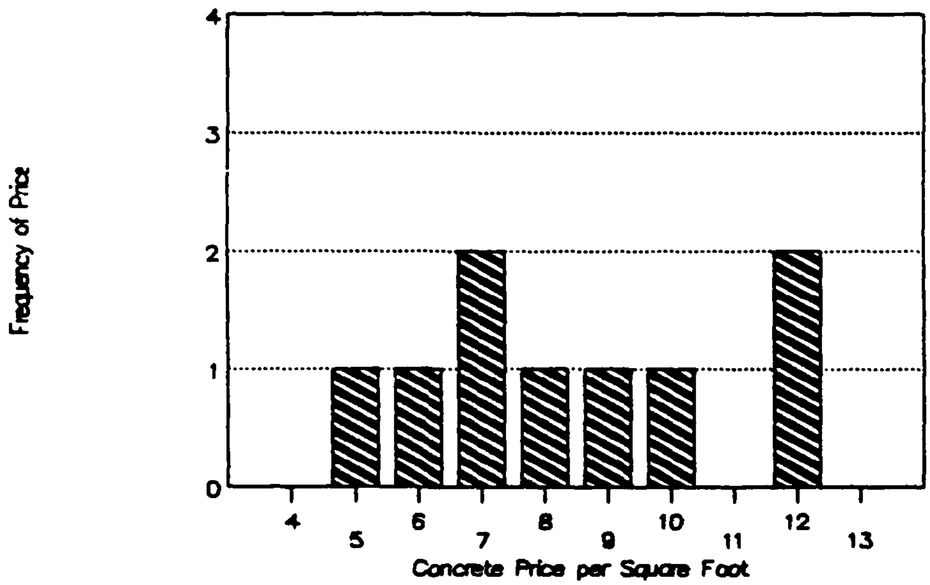

Figure 3. Frequency of Concrete Square Foot Costs for Administrative Facilities

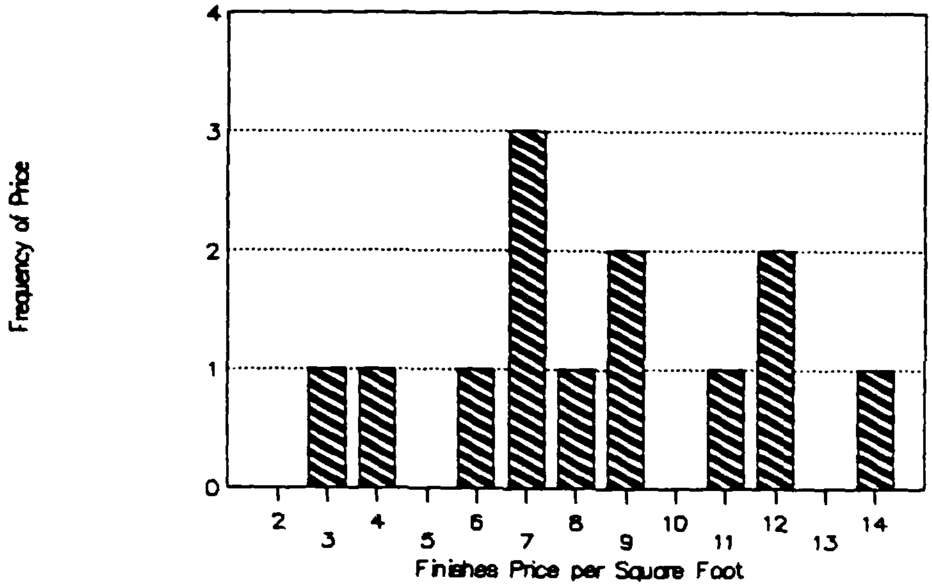

Figure 4. Frequency of Finishes Square Foot Costs for All Facilities

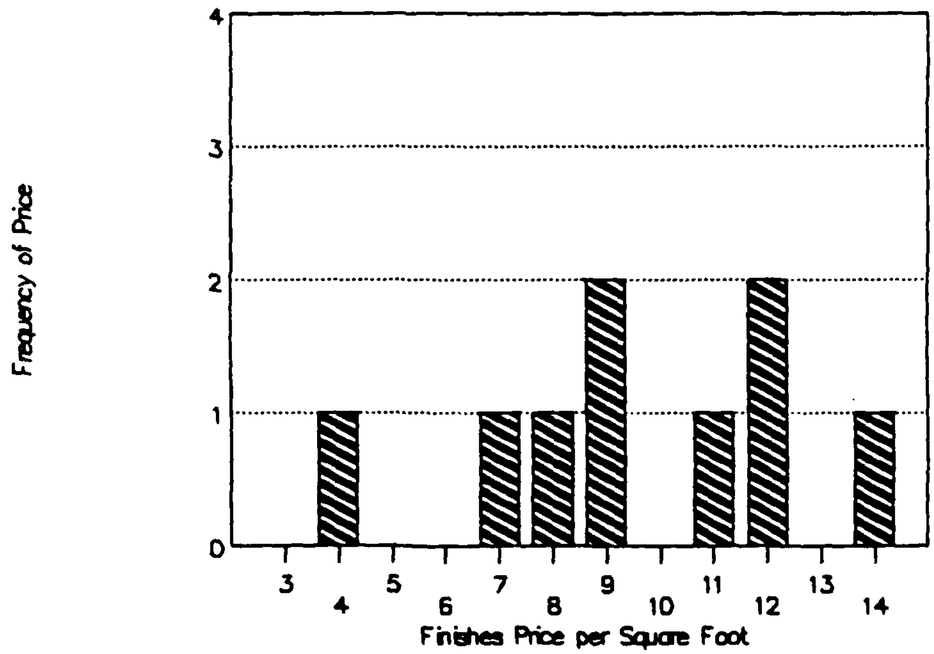

Figure 5. Frequency of Finishes Square Foot Costs for Administrative Facilities

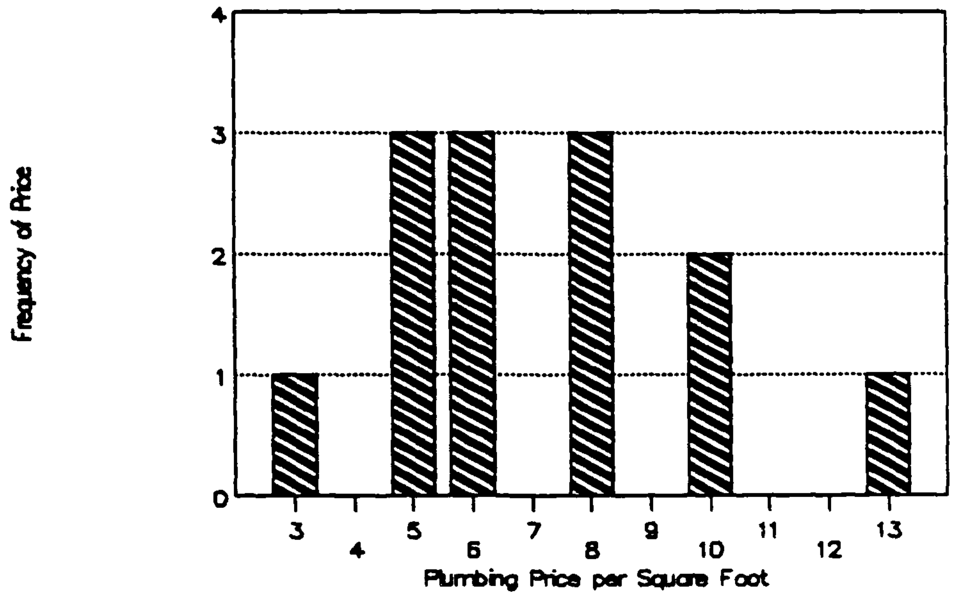

Figure 6. Frequency of Plumbing Square Foot Costs for All Facilities

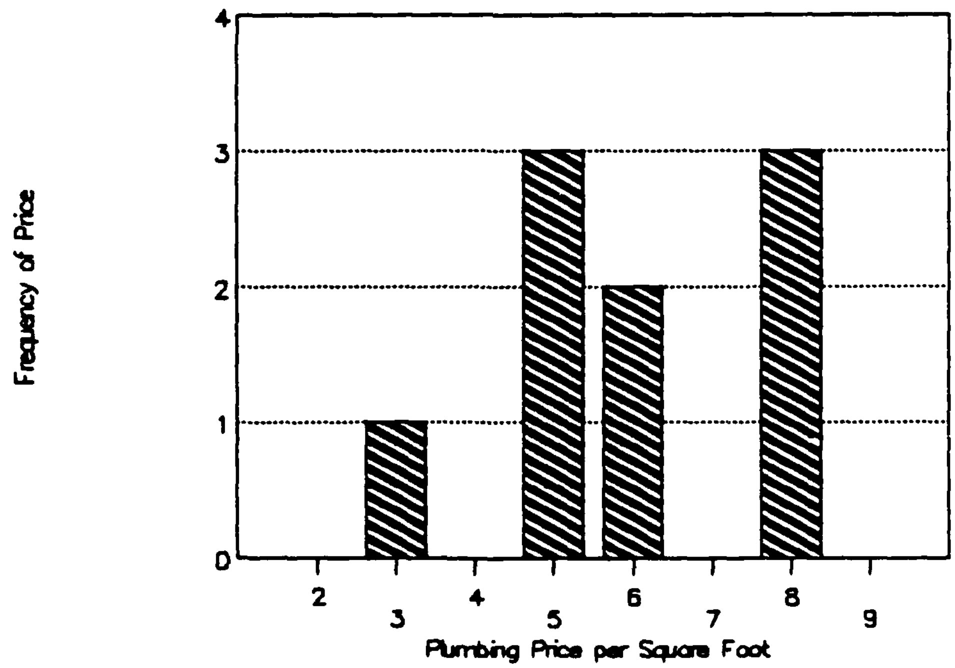

Figure 7. Frequency of Plumbing Square Foot Costs for Administrative Facilities

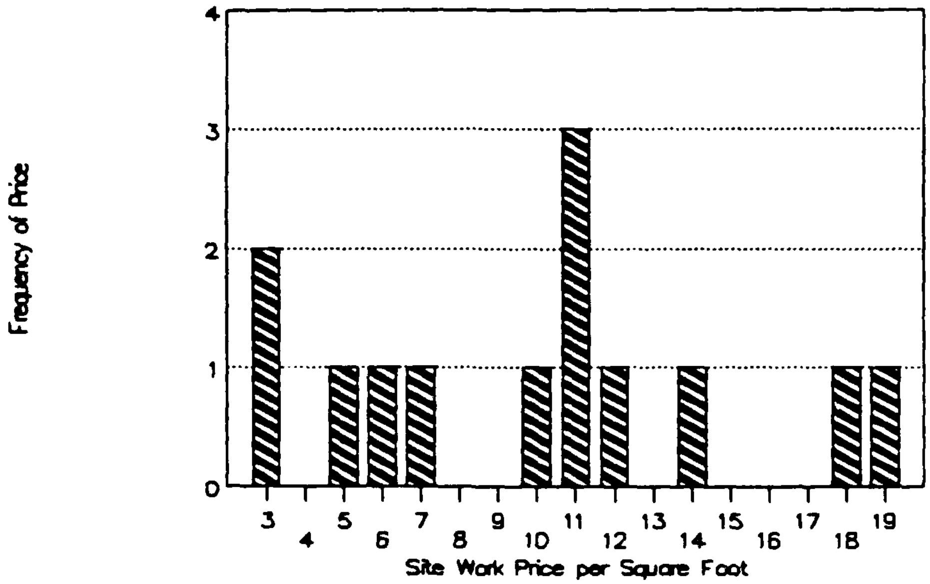

Figure 8. Frequency of Site Work Square Foot Costs for All Facilities

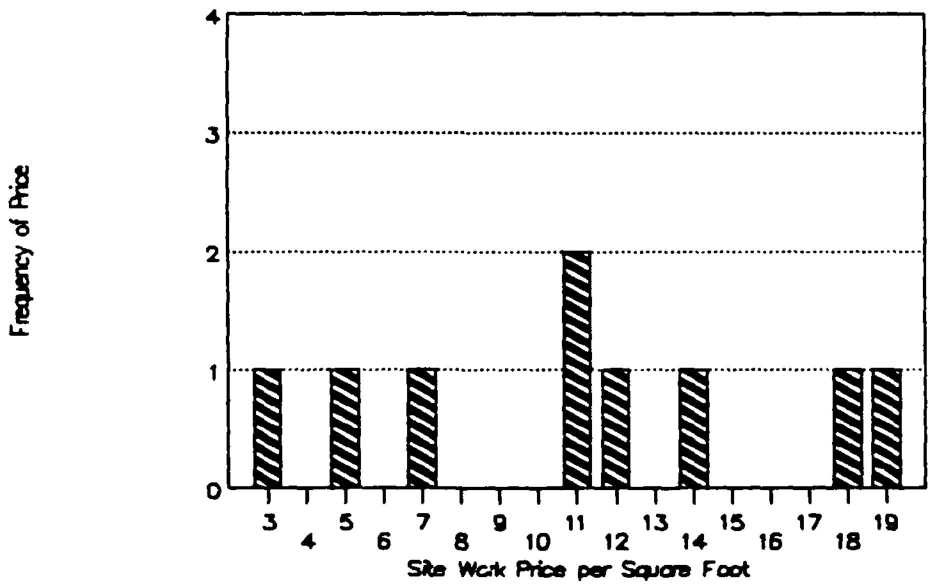

Figure 9. Frequency of Site Work Square Foot Costs for Administrative Facilities

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This research was designed to apply statistical techniques to localized construction cost data in developing an expected range of estimated costs for base-level construction projects. Historical contract costs for minor construction projects under 5,000 square feet were broken down into the sixteen divisions of the Construction Specification Institute format. These costs were statistically analyzed to determine an acceptable method of forecasting the expected low bid and a confidence interval of values as a measure of project acceptability.

The methods examined included mean square footage, summation of average division costs, summation of median division costs, bid simulation, multiple regression, and time-series forecasting. The techniques were tried on two test groups, all projects in the data base and administrative projects only. Although all of these methods can be used to develop a range of estimated costs, the more elements used and the more restricted the project classification, the better the estimate and the range of expected costs.

These methods require additional research utilizing a larger data base and comparing the results with several new projects to determine the validity.